



NLC - The Next Linear Collider Project

The Photon Collider at NLC

Jeff Gronberg/LLNL

Fermilab Line Drive

March 15, 2001

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.



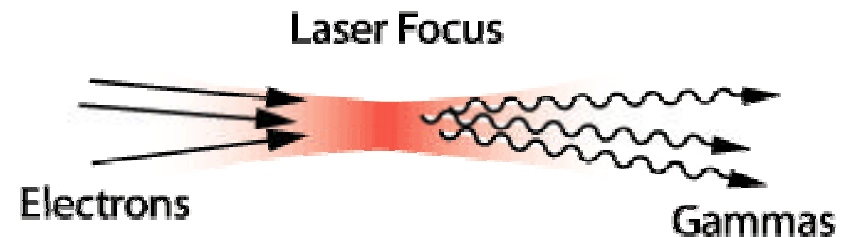
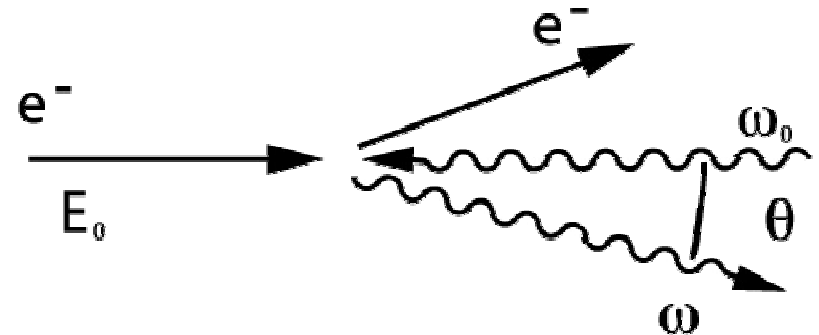
Outline

- Review the basic principles behind photon production through Compton back-scattering.
- Discuss the engineering required to actually realize a photon collider.
 - Lasers
 - Optics
 - Interaction Region design

Basic components exist (laser, optics, IR design)
Complete engineering design for Snowmass

Compton back-scattering

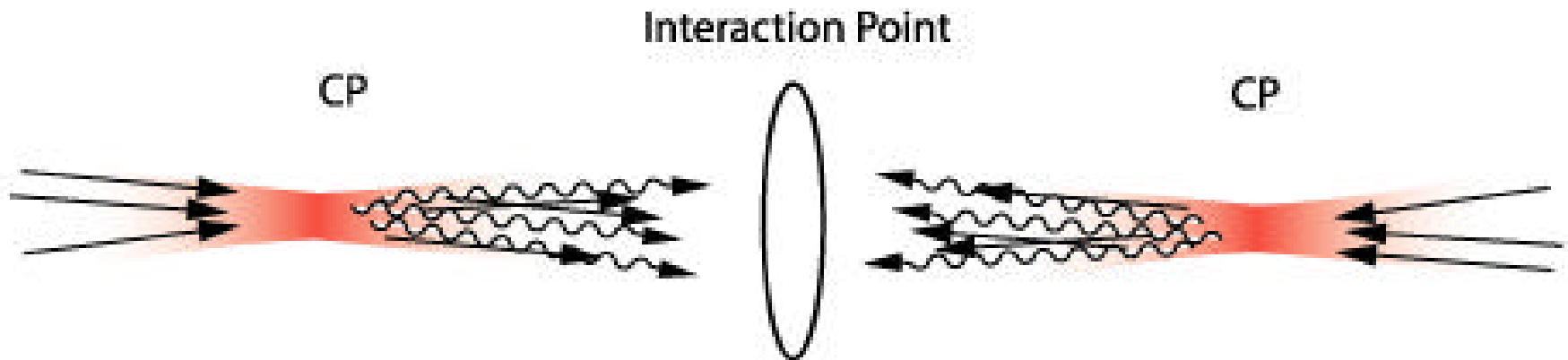
- Two body process
 - Correlation between outgoing photon angle and energy
 - Maximum energy when the photon is colinear with the incoming electron
- Proposed by Ginzburg et al. (1982) for producing a photon collider
 - Collide a high power laser pulse with an electron beam to produce a high energy photon beam





Gamma-Gamma collisions

- Since high energy photons are co-linear with the incoming electron direction they focus to the same spot.
 - Lasers are powerful enough to convert most of the incoming electrons
 - High energy $\gamma\gamma$ luminosity is large
- Low energy photons and electrons also travel to the IP and produce a tail of low energy interactions.
- The beam - beam interaction at the IP
 - Produces additional low energy beamstrahlung photons
 - Deflects the low energy spent electrons.





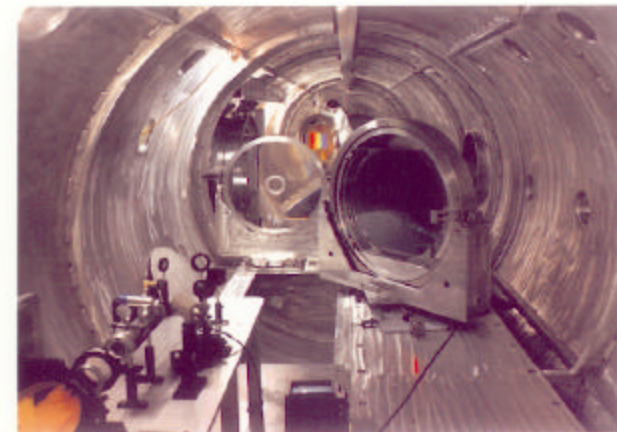
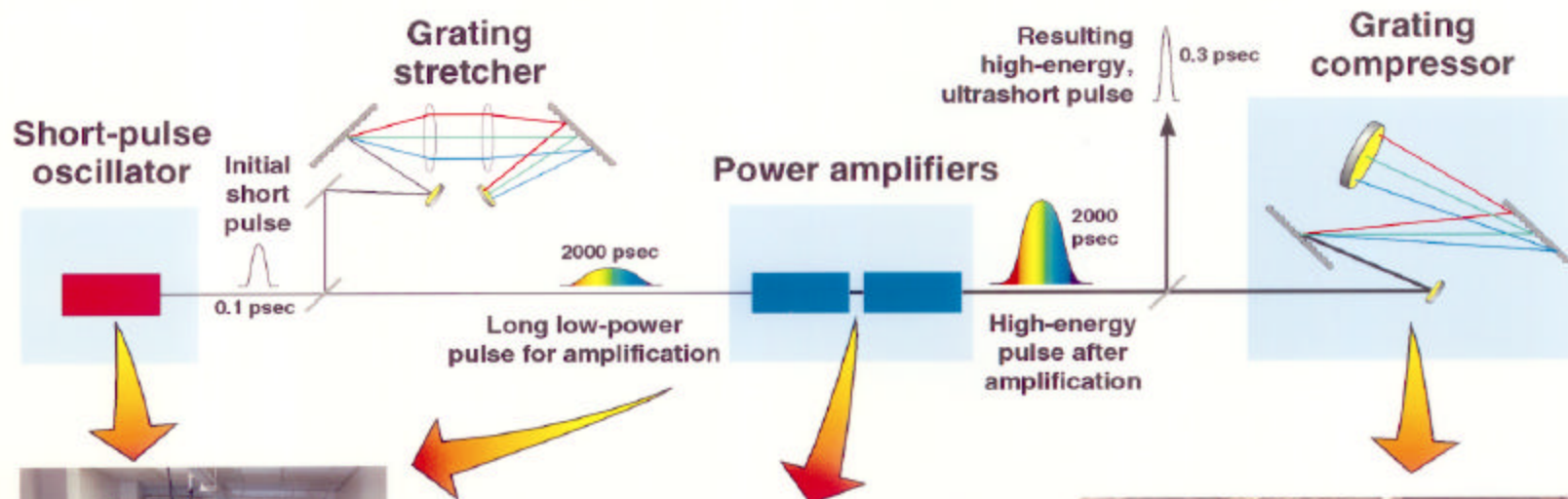
Full Team in Place

- **Lasers:**
 - Jim Early
 - John Crane
- **Optics**
 - Steve Boege
 - Lynn Seppala
 - Scott Lerner
- **Mechanical Engineering**
 - Ken Skulina
 - Knut Skarpas VIII
 - Leif Erikson
- **Accelerator Engineering**
 - David Asner
 - Pantaleo Raimondi
 - Andrei Seryi
 - Tor Raubenheimer
- **Physics**
 - Jeff Gronberg
 - David Asner
 - Solomon Obolu
 - Shri Gopalakrishna
 - Tohru Takahashi
 - NWU - FNAL
- **Project Management**
 - Karl van Bibber
 - Jeff Gronberg

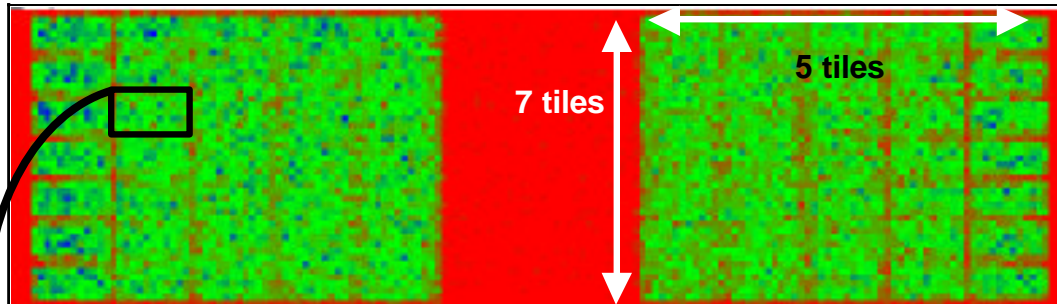
Lasers requirements

- Laser pulses of
 - 1 Joule, 1.8 ps FWHM, 1 micron wavelength
 - One for each electron bunch
 - 95 bunches / train x 120 Hz = 11400 pulses / second
 - Total laser power 10kW
 - 2.8 ns between bunches
- Requires:
 - High peak power (1 TeraWatt)
 - High Average power (10 kW)
 - Correct pulse format (95 pulses @ 2.8 ns spacing x 120 Hz)

Chirped pulse amplification allows high peak power picosecond pulses

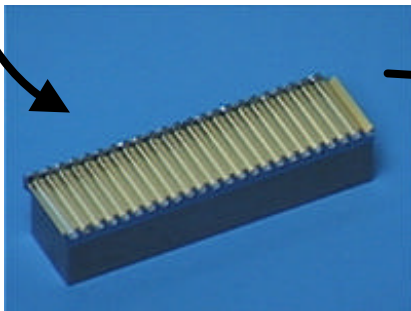


Diode pumping enables high average power
Matching diode output wavelength to the laser amplifier pump band gives 25% power efficiency

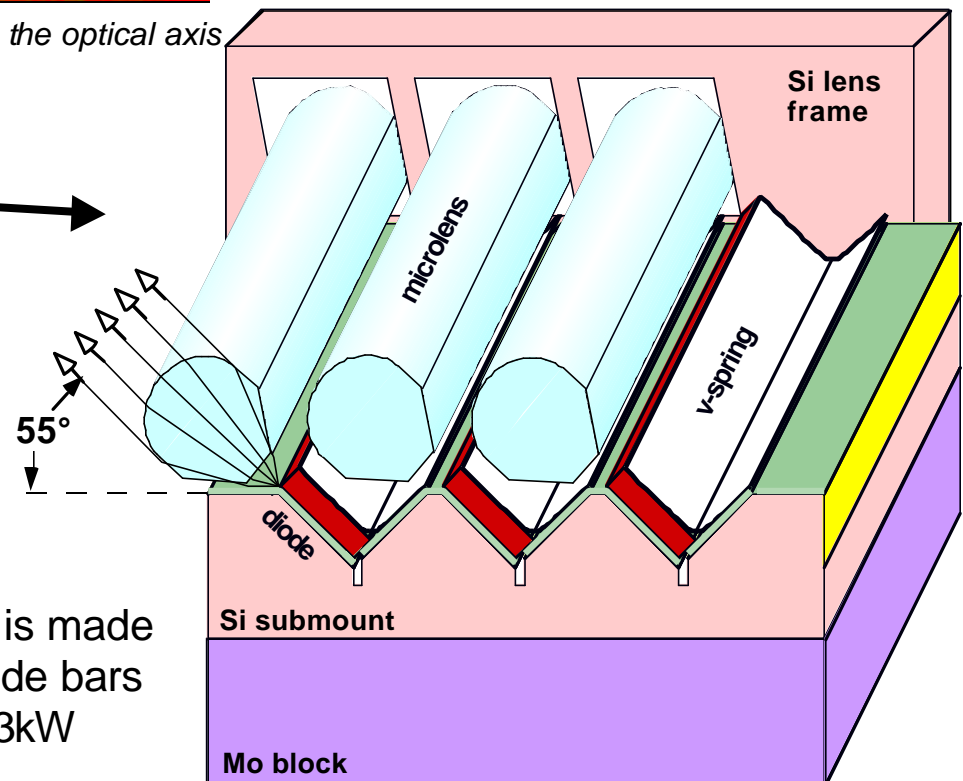


4 pairs of diode arrays like these are required for Mercury \Rightarrow 644 kW

Diode light distribution (green) obtained in a plane normal to the optical axis



Each array is made of $5 \times 7 = 35$ tiles per array \Rightarrow 161 kW

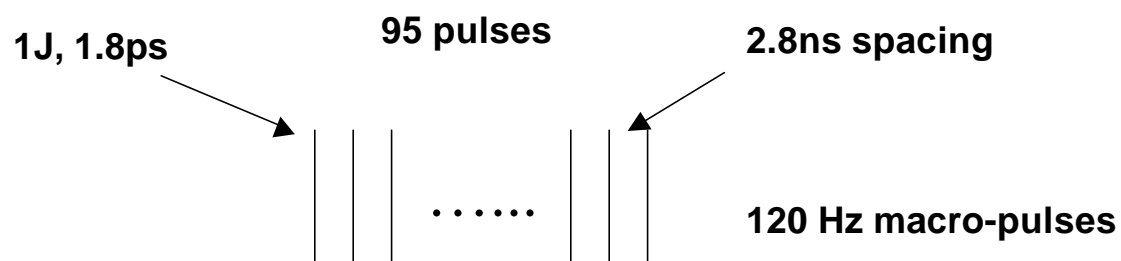


Each tile is made of 23 diode bars \Rightarrow 2.3kW



Pulse Format drives the Laser architecture

NLC bunch format



ZDR 1996

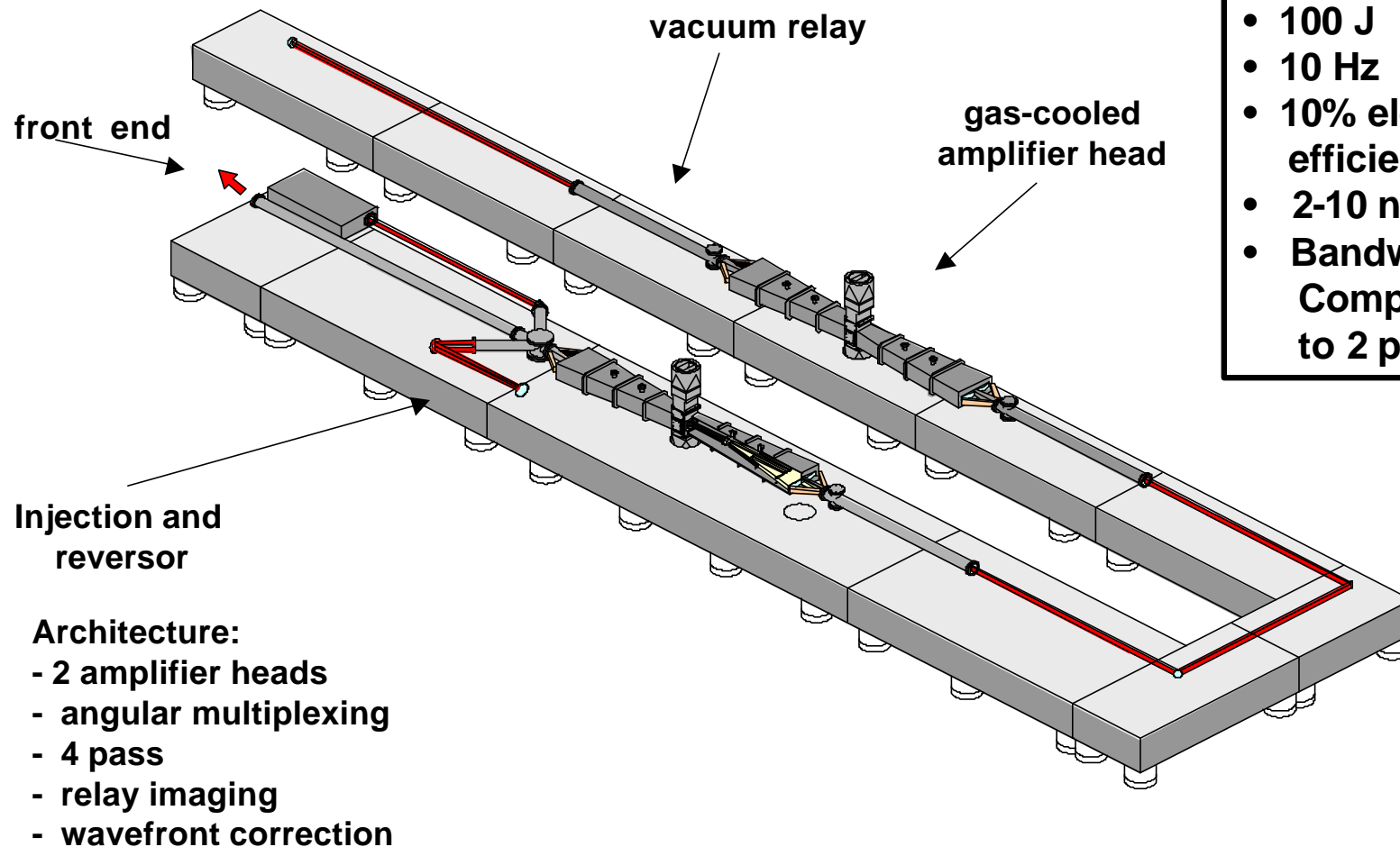
100 small lasers
1 J, 100 Hz
ns switches to spatially and temporally
Combine sub-pulses to macro-pulse

New Mercury option

12 larger lasers
100 J, 10 Hz
Simple 10 Hz spatial combiner
Break macro-pulse into sub-pulses



The Mercury laser will utilize three key technologies: gas cooling, diodes, and Yb:S-FAP crystals

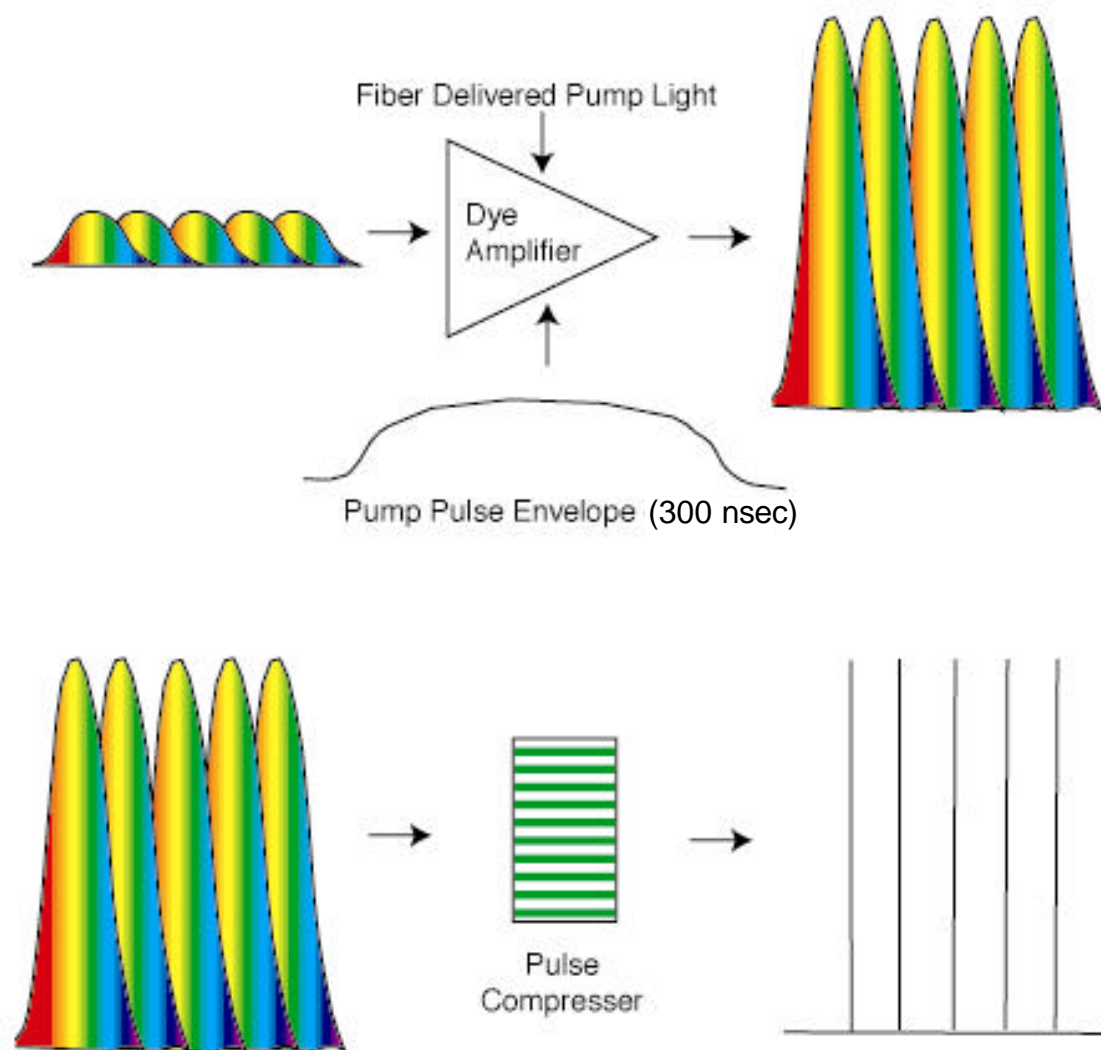


Goals:

- 100 J
- 10 Hz
- 10% electrical efficiency
- 2-10 ns
- Bandwidth to Compress to 2 ps

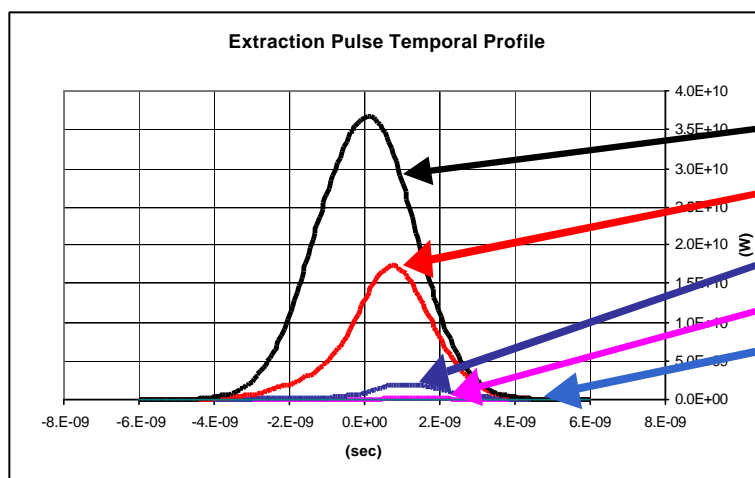
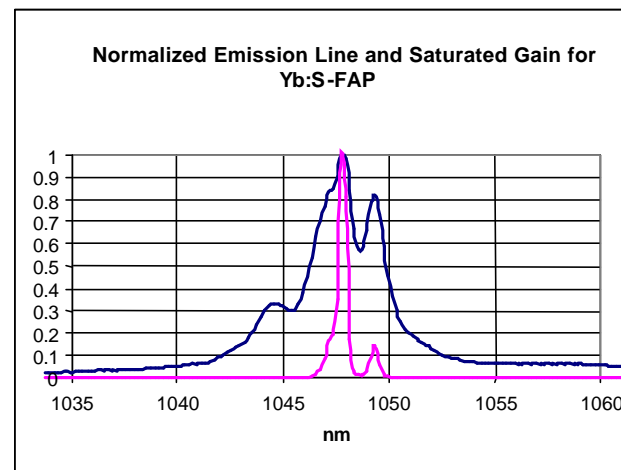
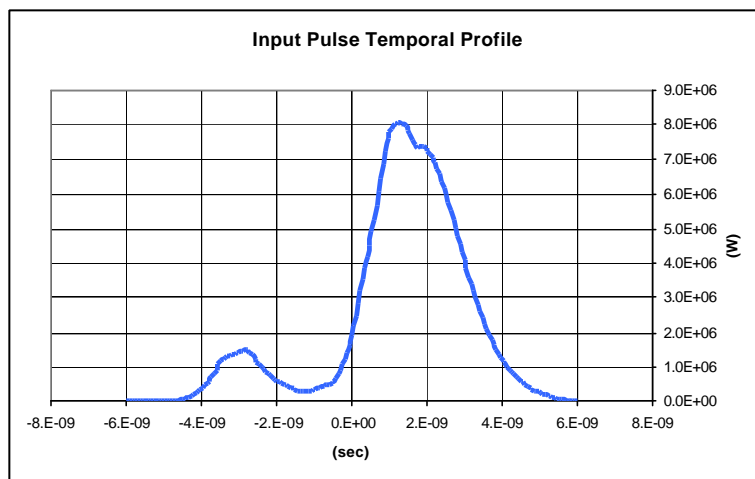


Wide band amplifier allows polychromatic components of the pulses to be linearly amplified. Subsequent re-compression gives short, separated pulses.



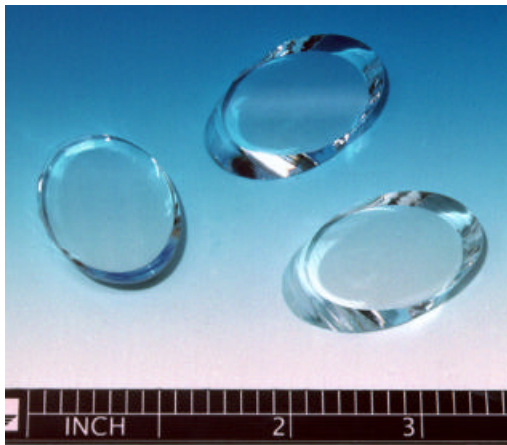
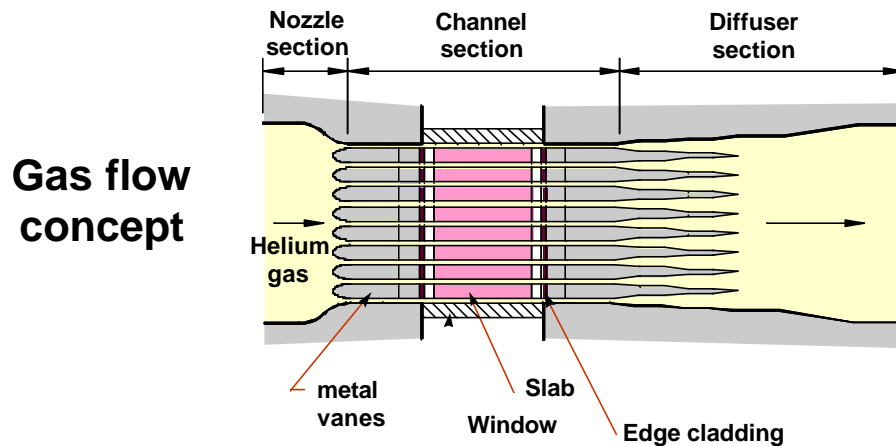


Appropriate spectral sculpting of the input pulse can lead to a linearly chirped gaussian output pulse (2 psec stretched output pulse case)

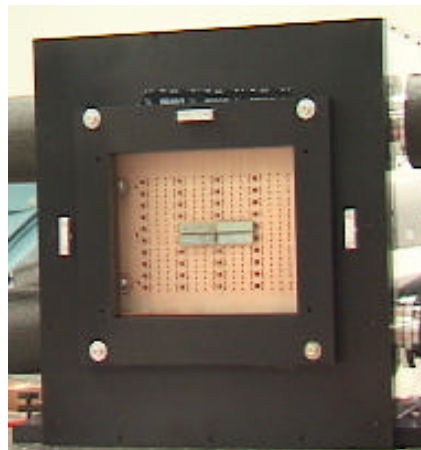


Pass 4 (output)
Pass 3
Pass 2
Pass 1
Input Pulse

We are developing diode-pump solid state lasers as the next-generation fusion driver - Mercury will deliver 100 J at 10 Hz with 10% efficiency.



**Yb:S-FAP
crystals**

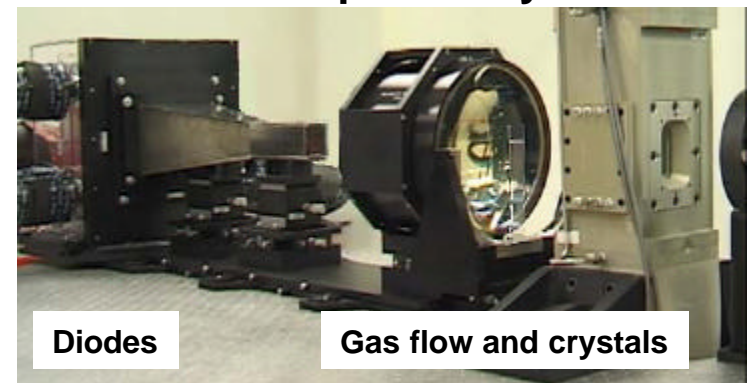


**Diode array
capable of 160 kW**

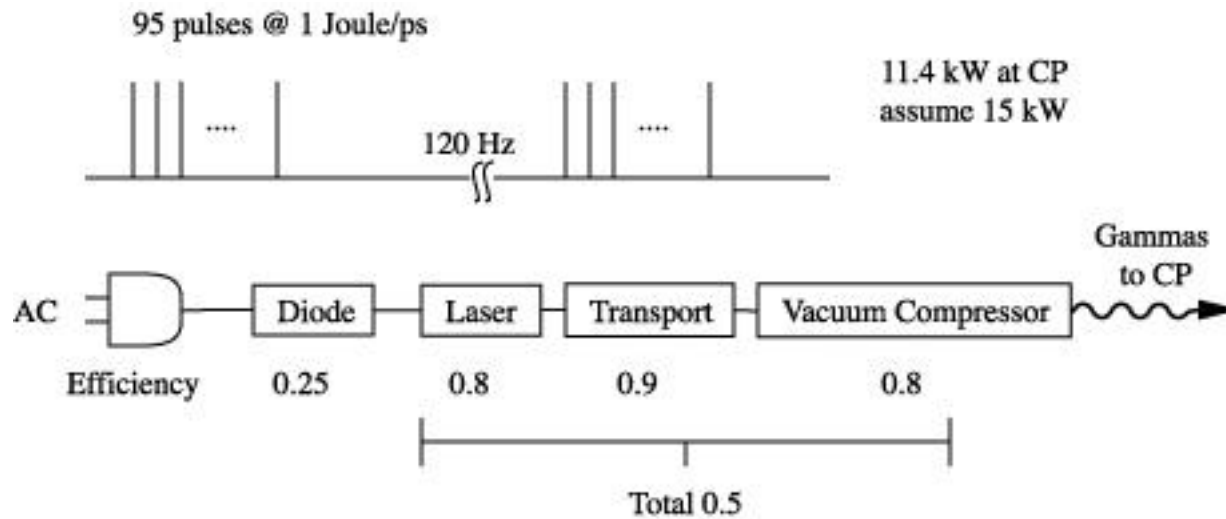
Mercury Lab



Pump Delivery



Diode requirements



w/ 100% contingency
@ \$5 / Watt

Total peak
diode power

$$N_{lasers} \cdot \frac{Energy / pulse}{e \cdot t_{upper}} = 12 \cdot \frac{100 Joules}{0.5 \cdot 10^{-3} sec} \cong 2.5 MW = \$24M$$

Average Power

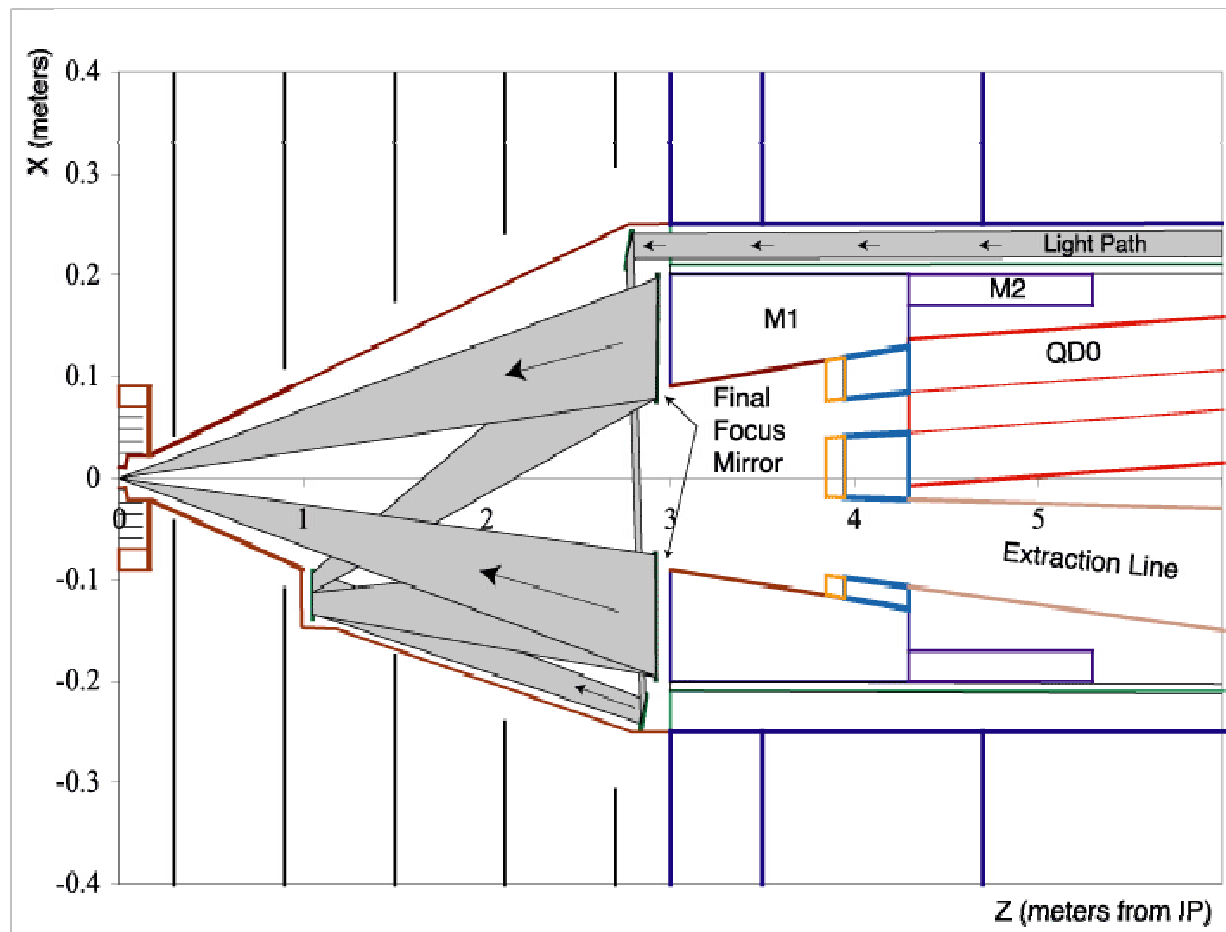
$$\frac{Total Power Required}{e_{Tot}} = \frac{15 kW}{0.1} = 150 kW$$

Optics and IR

- **Optics requirements**
 - Keep accumulated wave-front aberrations small
 - Prevent damage to optics from high power pulses
 - All regimes; ps, 300 ns, continuous
 - Prevent accumulation of non-linear phase aberration
 - Vacuum transport lines
 - Reflective optics - transmissive optics only where necessary
- **IR/Optics integration**
 - Optics must be mounted in the IR
 - All hardware required to accomplish this must not:
 - Interfere with the accelerator
 - Degrade the performance of the detector
 - Generate backgrounds

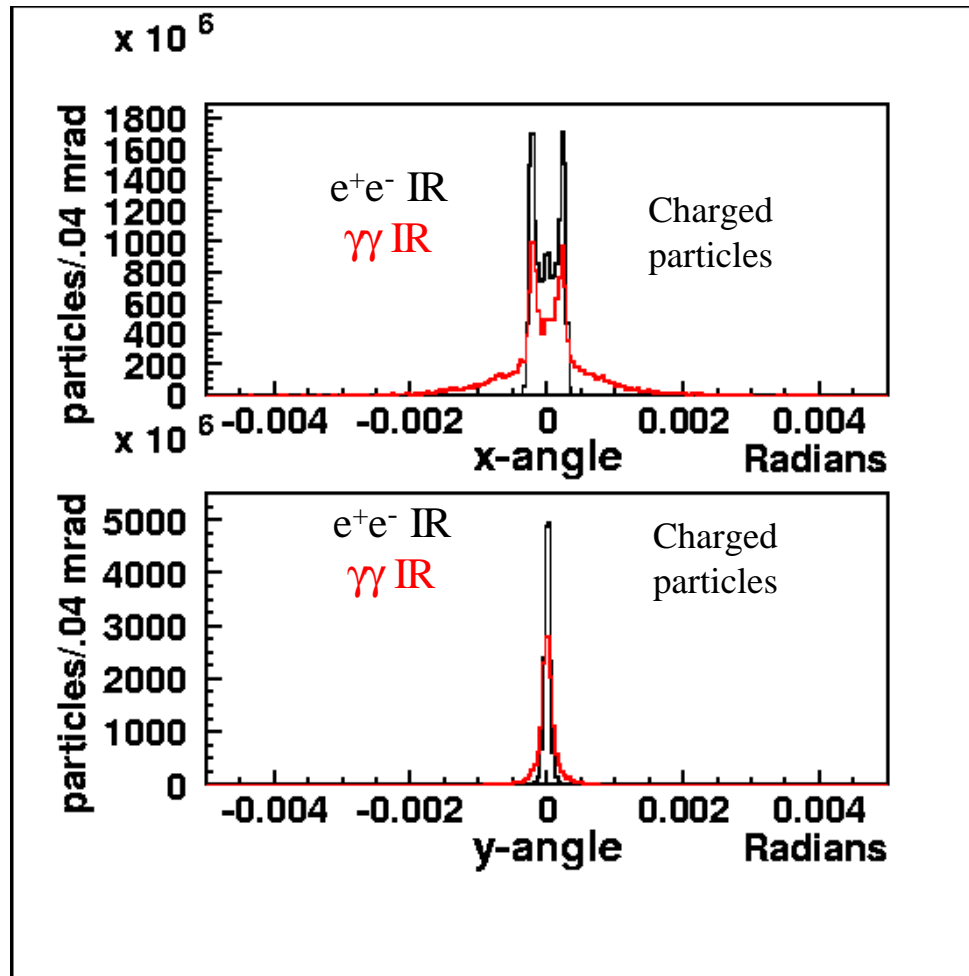
Focusing mirrors - tight fit

LCD - Large with new mirror placement



- Essentially identical to e^+e^- IR
- 30 mRad x-angle
- Extraction line ± 10 mRadian
- New mirror design 6 cm thick, with central hole 7 cm radius.
 - Remove all material from the flight path of the backgrounds

Disrupted Beam



- High Energy photons means low energy electrons.
 - Large beam-beam deflection
 - Large rotation in solenoid field
- Requires extraction line aperture ± 10 milliradians
- Leads to increase in crossing angle to avoid conflict between final quadrupole and extraction line.
- Zero field extraction line, no optics.



IR Background changes from e^+e^-

- Increased disruption of beam, Larger extraction line
 - ± 10 milliradians extraction line
 - Crossing angle increased to 30 milliradians to avoid conflict with incoming quad. Should be reduced to minimum when final design of quad is known.
 - First two layers of SVX now have line of sight to the beam dump
 - Fluence of neutrons 10^{11} /cm²/year
 - Need rad hard SVX
- Higher rate of $\gamma\gamma \rightarrow qq$, minijets
 - Still to be evaluated



Tesla bunch structure

	τ_B ns	N_B	f Hz	σ_z μm	N 10^{10}
TESLA-500	337	2820	5	300	2.0
NLC-500H	2.8/1.4	95/190	120	110	1.5/0.75

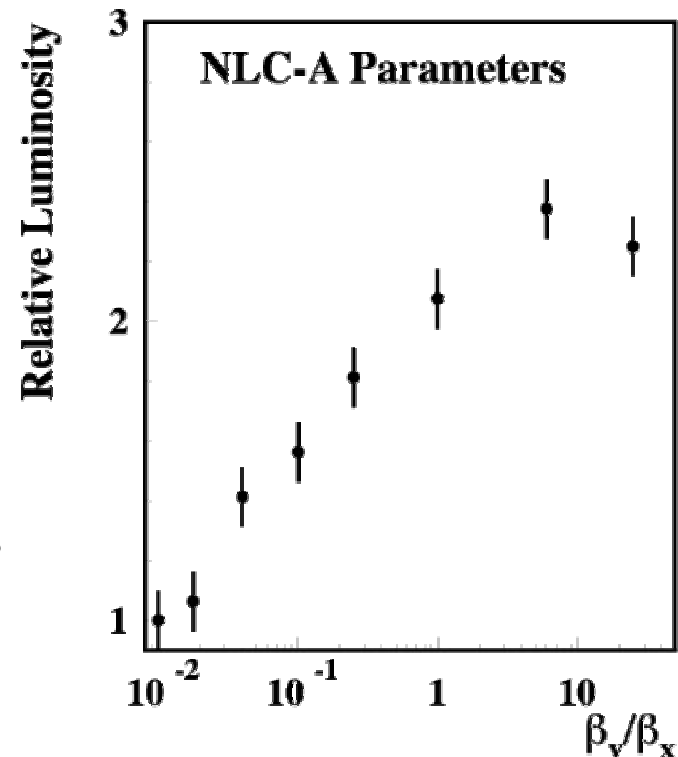
Tesla bunch structure is very different
Major impact on Laser Architecture

- 1 millisecond is the laser amplifier upper state lifetime
 - Tesla must produce 30 times as many pulses on that timescale
- Since most laser power goes unused they are investigating
 - Multipass optical cavities
 - Ring lasers
- No baseline design in TDR



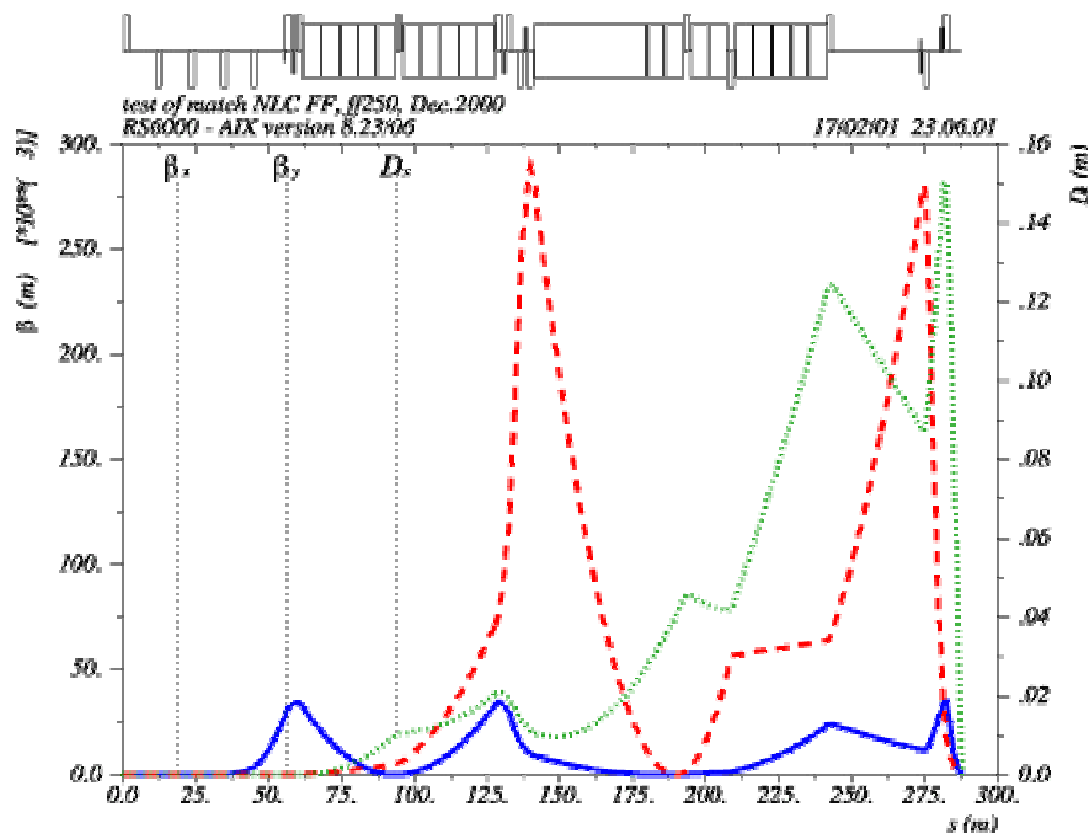
Accelerator differences

- None needed - Some desired
 - Rounder beams
 - Relaxes requirements on beam stabilization
 - Increases luminosity by factor 2
 - More bunch charge, fewer bunches
 - Most laser power unused no cost for increased bunch charge
 - Fewer bunches, more time between bunches
 - Laser architecture easier
 - Halving the number of bunches and doubling the bunch charge increases luminosity by factor 2
 - e^-e^- running
 - Electrons are easier to polarize
 - Reduce e^+e^- physics backgrounds
 - Reduce beamstrahlung photons





New Final Focus



- Maximally compatible with e+e- running.
- One new quadrupole after the big bend.
- Spot size 15nm x 60 nm.
- Luminosity increase of a factor ~ 2 .

Increase bunch charge

- Lasers prefer bunch spacing of 2.8 ns
 - Current 190 bunch 1.4 ns machine parameter sets are not optimal
- Tor Raubenheimer provides optimized machine parameters for $\gamma\gamma$
 - 95 bunches, 2.8 ns spacing
 - All other parameters as per NLC-A
 - Twice the bunch charge

In the high energy peak the $\gamma\gamma$ luminosity is now ~4 times higher than for the standard machine parameters

e^-e^- running

- Easy (sort of)
 - Changeover requires rotating all quads in one arm of the linac
 - Order 1 month required
 - Polarized electron production needed in the positron injection complex with positron target bypass
- The base e^-e^- luminosity is down a factor of 3 from the e^+e^- luminosity. The beam beam attraction become repulsion.
 - Beam-beam interaction has no effect of high energy $\gamma\gamma$ peak
 - Improved polarization increases luminosity in the high energy $\gamma\gamma$ peak
 - Most ee backgrounds reduced by a factor 3

Machine Optimization

- Basic design of photon collider exists.
- Detailed choices about machine configuration must be driven by physics analyses.
 - How important is electron polarization?
 - Must the low energy tail be suppressed?
 - Is it important to do Higgs runs on peak or can we take advantage of higher luminosity in the tail while running at max energy for SUSY / new physics searches.



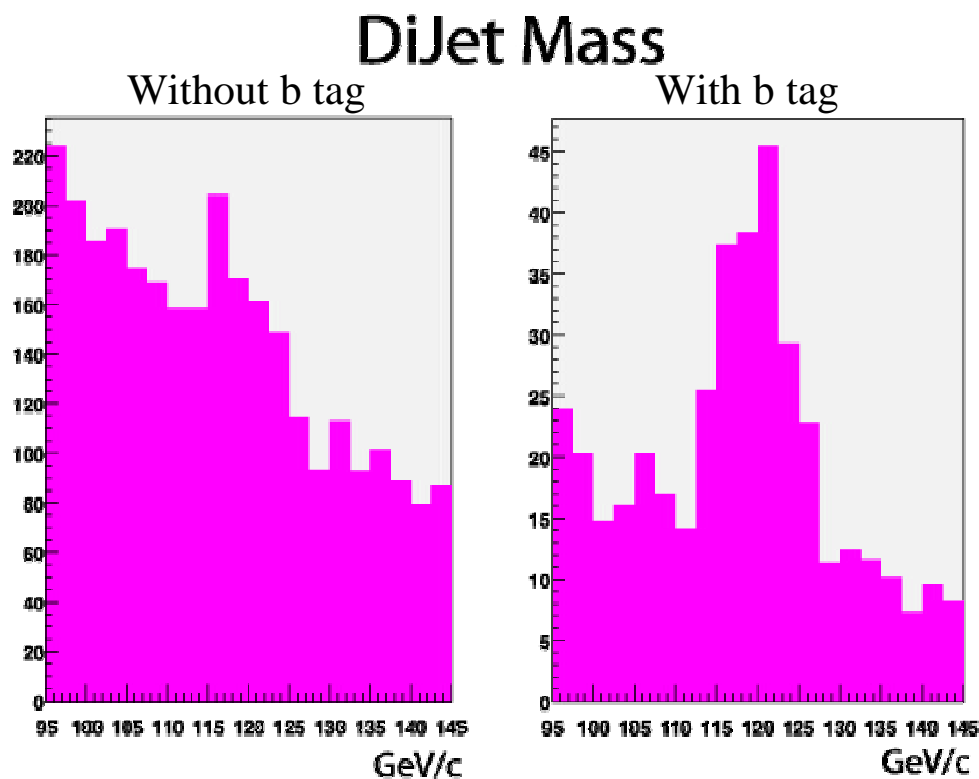
Ongoing Physics efforts

- For new machine parameters and round beams
 - ~ 1000 Higgs / year
- Evaluating Higgs @
 - 120, 140, 160 GeV/c mass
 - bb, WW, ZZ modes
- UC Davis students evaluating
 - $\gamma\gamma \rightarrow$ chargino pairs
 - $e\gamma \rightarrow$ Lightest SUSY partner
- Groundswell of interest in $\gamma\gamma$
- NWU and FNAL physicists have organized an international workshop on gamma-gamma interactions @ FNAL, March 14-17.
 - <http://diablo.phys.nwu.edu/ggws/>
- $\gamma\gamma$ parallel session @ JHU LC meeting next week
 - <http://hep.pha.jhu.edu/~morris/lcw>



Benchmark H[®] bb mode

- Full Luminosity simulation interfaced to pandora_pythia.
- For old NLC-B parameters 1 year running.
- For new parameters and round beams 2 months running.



Conclusion

- Livermore is proceeding with a complete engineering design of a photon collider for Snowmass
- No show stoppers have been found for either the laser technology, optics or the IR integration

All enabling technologies exist
Task is mainly engineering now